

Discovery of the strongly eccentric, short-period binary nature of the B-type system HD 313926 by the MOST satellite^{*}

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ABSTRACT

The MOST photometric space mission discovered an eclipsing binary among its guide stars in June 2006 which combines a relatively large eccentricity $e = 0.20$ with an orbital period of only 2.27 days. HD 313926 appears to consist of two early-type stars of spectral type B3 – B7. It has a largest eccentricity among known early-type binaries with periods less than 3.5 d. Despite the large components indicated by its spectral type and light curve model, and its short period, the orbit of HD 313926 has not yet circularised so it is probably very young, even compared to other young B stars.

Key words: stars: eclipsing – stars: binary – stars: evolution – photometry: space-based

1 INTRODUCTION

Tidal dissipation is known to lead to circularization of close binary star orbits. In hot (radiative equilibrium) stars, the dominant dissipative mechanism is thought to be the dynamical tides. Its efficiency is expected to show a very strong dependence on the relative size of the stars, with the time scale $t_{circ}^R \propto (r/a)^{-21/2}$ (r is the radius and a is the mean separation of the components), even stronger than for cool (convective equilibrium) stars, $t_{circ}^C \propto (r/a)^{-8}$ (Zahn 1975, 1977, 2005). However, coefficients in the two proportionalities differ by many orders of magnitude with the latter ef-

iciency being much higher than the former. Therefore, as pointed out in a review by Zahn (1992), a low-mass, cool secondary component can contribute most of the dissipation so that the range of possibilities here is very wide.

The main tool in studies of orbit circularization is the period – eccentricity distribution and its evolution with time. A whole meeting (Duquennoy & Mayor 1992), jokingly referred to by its editors as “The $e - \log P$ Workshop”, was devoted to this subject. Twelve years after that meeting, a focussed workshop (Claret, Gimenez & Zahn 2005) discussed apparent limitations of the current theories which point at a need of additional, more efficient dissipation mechanisms in addition to those included in the classic theory of Zahn. The discovery of a short-period eccentric binary by the MOST space mission adds an observation to an interesting region of $e - \log P$ parameter space.

^{*} Based on data from MOST, a Canadian Space Agency mission jointly operated by Dynacon Inc., the University of Toronto Institute for Aerospace Studies and the University of British Columbia, with the assistance of the University of Vienna), and on data from the David Dunlap Observatory, University of Toronto.

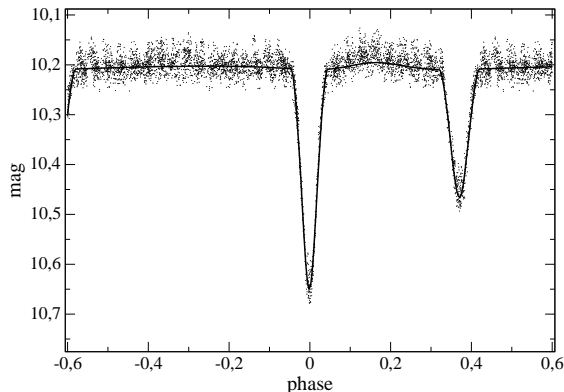


Figure 1. The MOST photometry of HD 313926 in 2-min bins, phased to a period of 2.27038 d. The solid curve is the best fit from our light curve synthesis model.

2 MOST OBSERVATIONS

MOST (Microvariability & Oscillations of STars) is a microsatellite housing a 15-cm telescope which feeds a CCD photometer through a single custom broadband optical filter (350 - 700 nm). The pre-launch characteristics of the mission are described by Walker, Matthews et al. (2003) and the initial post-launch performance by Matthews et al. (2004). MOST is in a Sun-synchronous polar orbit (820 km altitude) from which it can monitor some stars for as long as 2 months without interruption. The instrument was designed to obtain highly precise photometry of bright stars through Fabry Imaging. Since launch, its capabilities have been expanded to obtain photometry of the guide stars used to orient the spacecraft, with the same time coverage as the Primary Science Target.

HD 313926 ($V = 10.7$, sp. B9) was one of the guide stars in the field of the Wolf-Rayet star WR 111, which was the primary target observed by MOST in June 2006. CCD readings were obtained in rapid sequence with an exposure time of 1.5 s, set by the Attitude Control System (ACS) requirements of spacecraft pointing. For the science measurements, these images were stacked on board the satellite, so that the effective exposure time was 15 s, at a sampling rate of once every 20 s. The final MOST photometry consists of 4,906 readings binned at intervals of 2 – 6 minutes, covering about 23 days of nearly continuous monitoring, with practically no gaps in time.

The eclipsing binary nature of HD 313926 was obvious early on in the observations. The photometric data were phased to the period $P = 2.27038$ d (see ephemeris below), as shown in Figure 1. The photometry can be downloaded from the MOST Public Data Archive on the Science page of www.astro.ubc.ca/MOST.

Like many faint MOST guide stars, rather little is available in the literature about HD 313926. We summarise the published characteristics of the star in Table 1. The Tycho-1 (ESA 1997) parallax is of very low quality and Simbad does not give a source for the listed spectral type of B9. The star is almost exactly in the Galactic equator, so the colour index $B - V = 0.38$ from Tycho-2 (Høg et al. 2000) may be due to large interstellar reddening. If the star is nearby, without any reddening, then the colour corresponds to ap-

Table 1. Information from the literature about HD 313926. Mean standard errors are given in parentheses (note: Tyc-1 = Tycho-1, Tyc-2 = Tycho-2).

Parameter	Data
Designations	HD 313926 CPD-21°6659 GSC 06276-01849
Position (J2000)	$\alpha = 18:09:07.93$, $\delta = -21:28:24.8$
Galactic coordinates (deg)	$l = 9.12$, $b = -0.85$
Photometry (Tyc-1)	$B - V = 0.372$
Photometry (Tyc-2)	$V_T = 10.602$ (0.062) $B_T = 11.059$ (0.062) $B - V = 0.388$
Data from Simbad	$V = 10.7$, Sp Type: B9
Parallax (Tyc-1)	$\pi = 90.4$ (55.0)
Proper motion (Tyc-2)	$PM_{RA} = 0.8$ (2.8) mas/yr $PM_{dec} = -1.6$ (2.9) mas/yr

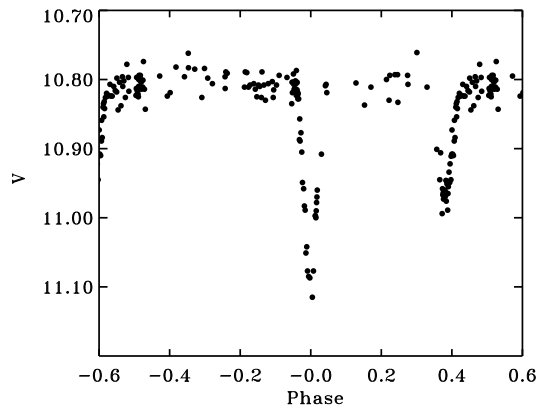


Figure 2. The phased ASAS light curve of HD 313926 for the 2003 season (JD 2,452,743 – 2,452,952).

proximately F3V. Therefore, the published spectral type of B9 requires verification.

3 THE BINARY EPHEMERIS

It is clear from Figure 1 that HD 313926 is an eccentric binary, with the secondary eclipse at phase 0.38 relative to the primary eclipse at phase 0.00.

HD 313926 had been observed photometrically by the ASAS photometric survey (Pojmański & Maciejewski 2005; Paczyński et al. 2006), but the large displacement of the secondary eclipse went unnoticed in this survey. The available V -band ASAS observations (482 in number) were collected during five consecutive seasons between June 2001 and July 2004. Typical data are shown in Figure 2, from the 2003 season. Note the difference in phase coverage of the ground based data spanning 209 days compared to that of the MOST data in Figure 1 collected over only 23 days. The depths of the eclipses are different in Figures 1 and 2 because of the differences in the filters used for the respective photometric measurements.

The ASAS photometry permits determination of three seasonal moments of primary eclipses and, as a result, an improvement of the primary eclipse timing solely from the MOST data (Table 2). We determine from the MOST and ASAS data an ephemeris of:

$$Min I = 2,453,893.0710(15) + 2.27038(22) \times E$$

Table 2. Eclipse timing for HD 313926 (A = ASAS, M = MOST).

JD pri	E	O-C (d)	JD sec	Sec ph.	Source
2,452,054.066	-810	+0.002	2,452,054.920	0.377	A 2001
2,452,362.828	-674	-0.007	2,452,363.695	0.379	A 2002
2,452,846.432	-461	+0.006	2,452,847.300	0.385	A 2003
2,453,893.071	0	0	2,453,893.912	0.370	M 2006

where the errors in the last significant digits are given in parentheses. There is no clear indication of any apsidal motion in the secondary eclipse times from the ASAS and MOST data.

4 LIGHT CURVE SYNTHESIS

In the MOST measurements, the primary eclipse is about 0.45 mag. deep and the secondary eclipse about 0.25 mag. deep. Both eclipses are relatively short and partial so that a light curve synthesis solution is rather poorly constrained. A preliminary solution of the MOST light curve has been obtained with the program PHOEBE (Prša & Zwitter 2005), which is a convenient interface to the popular Wilson-Devinney light curve synthesis code.

Because the spectroscopic mass ratio is unknown, we assumed that the system consists of identical-mass components, $q = 1$, which is basically the “default” value. There is very little information in the light curve (except the weak ellipsoidal variability apparent in Figure 1) to constrain q . The equal-mass assumption is spectroscopically testable (see Section 5 below). However, most of the parameters in the solution depend only weakly on the assumed mass ratio. We note that the two stars differ in their surface brightness. The two stars have similar dimensions, but the primary component (eclipsed at primary minimum) appears to be slightly brighter and thus also brighter for similar radii; therefore, the components cannot be both simultaneously on the Main Sequence (although our solution with $q = 1$ must be treated with considerable reservation).

The best fit, shown in Figure 1, with parameters listed in Table 3, reproduces the observed light curve quite well. In particular, the elliptical orbit causes a stronger ellipsoidal distortion of the components at the first maximum near phase 0.15. The components at that phase are closest to each other and thus most deformed.

To check for a presence of systematic deviations from the light curve model in Figure 1, both in terms of possible stellar variability and in terms of imperfections of the light curve model (which would show at the frequency 0.44 cycles per day), we analyzed the periodic content of the residuals of the MOST data from the light curve model. Figure 3 shows the Fourier amplitude spectrum. The spectrum does not show any variability beyond instrumental effects due to modulation of scattered Earthshine in the MOST instrument focal plane as MOST’s Sun-synchronous orbit carries it above a similar albedo feature on the Earth after 1 day. None of these are aliases due to gaps in the data. The dominant peak occurs at a frequency of 2 cycle/day, with another weaker peak at 1 c/d. The other prominent peaks occur at the MOST satellite orbital frequency of 14.1994 c/d ($P = 101.4$ min) and cycle/day side lobes.

Table 3. The preliminary geometric parameters of HD 313926. The radii r are in units of the mean separation and the luminosities L are in units of the total flux.

Parameter	Value	rms error
Mass ratio q	1.0	fixed
Inclination [deg]	82.8	0.1
Eccentricity	0.209	0.001
Long. periastr. ω [rads]	2.85	0.02
r_1	0.157	0.002
r_2	0.160	0.002
L_1	0.580	0.003
L_2	0.420	0.003

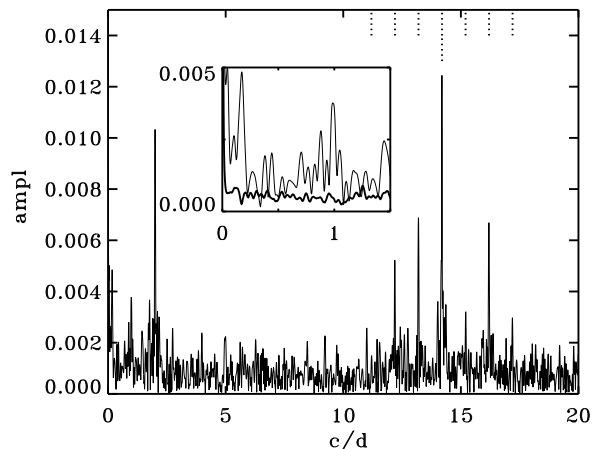


Figure 3. The Fourier-amplitude spectrum of residuals of the MOST photometry from the theoretical light curve (Figure 1). The spectrum shows only known sky background modulation artefacts due to MOST’s orbit (14.1994 c/d and 1 cycle/day modulation of the scattered Earthshine, marked by dotted tick marks in the upper part of the figure). The inset is an expanded plot of the low-frequency end of the spectrum, showing no synthesis model imperfections at the binary orbital frequency of 0.44 c/d or its harmonics. The thick line in the inset gives the error level; it is not plotted on the main diagram for clarity, but is similar in height throughout the whole spectrum.

5 SPECTROSCOPY OF HD 313926

A few classification-resolution spectra of HD 313926 were obtained with the 1.88m telescope of the David Dunlap Observatory (DDO), at a mean wavelength of 4200 Å, covering the region 3900 – 4650 Å with a resolution of about 1.2 Å. Because the star is visible from DDO at an elevation of only 25 deg above the southern horizon, over the very bright Toronto sky, the spectra are of relatively low quality with the strongly attenuated blue part and with a large noise due to the bright background subtraction. Our classification must be considered very preliminary, to be confirmed from a spectrograph in the southern hemisphere.

We have been able to confirm the early type of the components from the presence of the He I lines $\lambda 4387$ and $\lambda 4471$. The range of admissible spectral types is B3 to B7, which is even earlier than given by Simbad. Therefore, the binary appears to consist of massive, large stars, and the large $B - V$ colour must be due to the interstellar reddening.

A simple reality check on the size of the components, from Kepler’s Third Law and the geometrical elements in Table 3, as well as the main sequence mass – radius relation, suggests components with radii of about 4–6 R_\odot and masses

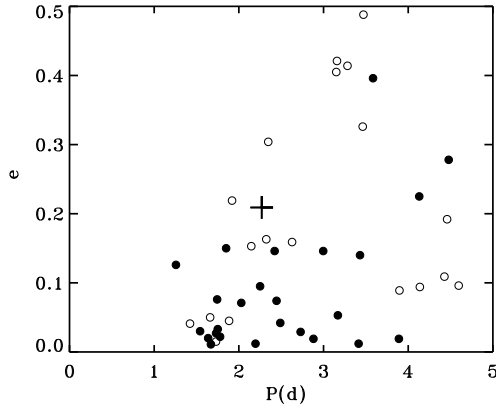


Figure 4. The distribution of the eccentricity e as a function of the orbital period P for close binaries, based on the catalogue of Hegedüs et al. (2005). Filled circles are binaries of spectral types O to B, while open circles are of types A to G. HD 313926 is marked by a cross.

of $10 - 15 M_{\odot}$. These ranges are consistent with spectral types of B2 to B5.

A thorough radial velocity (RV) study of HD 313926 would be useful. This calls for a 1.5–2m-class telescope in the southern hemisphere with a spectrograph of resolving power $R \sim 10,000$. Such a study would provide masses and absolute dimensions, permitting a full characterisation of the system. Based on the MOST light curve, the RV semi-amplitudes are expected to be of the order $K_1 \simeq K_2 \simeq 250$ km/s for mid-B stars like those inferred to be in HD 313926 (~ 150 km/s for mid-F stars). However, the overall solution will still not be extremely accurate because of the partial eclipses.

6 THE LARGE ORBITAL ECCENTRICITY OF HD 313926 IN PERSPECTIVE

Close binaries with similarly short periods and large eccentricities do exist, but for periods around 2 days, systems earlier than A0 have eccentricities typically below $e \simeq 0.15$. In Figure 4, we show the distribution of measured values of e vs. orbital period P for periods less than 5 days based on data from the most recent version of the Hegedüs et al. (2005) catalogue. The figure suggests that the upper envelope for early-type stars may be flatter than that for spectral types later than A0; for late spectral types of the same orbital period, stars are smaller and the tidal dissipation correspondingly weaker. HD 313926, of spectral type B3 – B7, lies near the extreme limit of eccentricity, compared to 22 other studied early-type stars with periods less than 3.5 d (of which 16 have $e < 0.1$).

In summary, HD 313926 defines a new position of the upper envelope for eccentricities of early-type stars at short orbital periods. Although all early-type stars are young, this pair of stars may be very young compared to the other youngsters. Unfortunately, we have no idea what was its initial eccentricity, to judge how much the orbit may have evolved in a short time. With the current preliminary geometrical parameters, we also cannot predict how long the circularization process for HD 313926 would take. The sys-

tem definitely requires further attention in efforts to estimate the circularization rates in massive, early type stars.

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